

# Water Management of Trickle and Furrow Irrigated Narrow Row Cotton in the San Joaquin Valley

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## ABSTRACT

**T**RICKLE and furrow irrigation were used on three field experiments on water management with narrow row (0.5 m) cotton. The experiments were conducted in the California San Joaquin Valley on Panoche clay loam soil from 1981 through 1983. The trickle irrigation regimes varied from two irrigations per week to one irrigation/2 weeks. The furrow irrigation regimes varied from no postplant irrigations to three seasonal irrigations. Lint yields ranged from 601 to 2,145 kg/ha. Total water application amounts (preplant and seasonal irrigations plus effective precipitation) of at least 650 mm were necessary to maximize lint production with the narrow rows at this location. Evapotranspiration was between 650 and 700 mm for maximum lint yields of 2,000 kg/ha. When verticillium wilt was not present, the lint yield of two newer Acala varieties (SJC-1 and DPL-90) was not better than the standard Acala variety (SJ-2). Trickle irrigation may reduce soil evaporation losses by as much as 75 to 100 mm when the irrigation tubing is spaced 2.0 m apart. No lint yield differences between trickle and furrow irrigation methods were found for narrow row cotton when irrigation management resulted in minimum soil water deficits.

## INTRODUCTION

Cotton is an important economic crop in the Southern and Southwestern United States. Most of the cotton from west Texas to California is irrigated since precipitation in these semiarid and arid regions is insufficient for economic production. Cotton has traditionally been grown in wide rows spaced from 0.97 to 1.03 m apart. Cultural management and harvesting machinery have been primarily adapted to these row spacings across the wide climatic zones throughout the cotton belt.

Cotton row spacing less than 1.0 m, under "adequate"

water supply, has been shown to increase yield by 10 to 30% (George et al., 1978). Additional benefits have included increased earliness; improved pink bollworm management; improved secondary pest management; improved verticillium wilt management; reduced production inputs of chemicals, water, and fertilizer; and improved potential for double-cropping in some areas. When managed for "early" production, narrow row cotton has been reported to require less irrigation while reducing maturation requirement by one month.

The major disadvantages of narrow row cotton culture have been related to harvesting. Generally, row spacings less than 0.76 m require "stripper" harvesting (either finger or brush stripping); however, the "picker" harvesting method has been successfully adapted to the 0.76-m row spacing by using a 2-row harvester to pick alternate rows, using a 2.29-m wheel spacing. Several commercial brush strippers have been developed to harvest four rows of either 0.50- or 0.76-m row spacing. When stripper harvesting methods are utilized, harvest trash is increased, resulting in increased ginning costs. In addition, stripper harvesting can affect cotton grade and classification (Kerby et al., 1986).

The recently published ASA monograph, *Cotton* (Kohel and Lewis, 1984), does not discuss management or cultural requirements of narrow row cotton production systems except for harvesting requirements. Nevertheless, narrow row cotton production systems have been widely studied across the cotton belt (Longnecker et al., 1970; Wilkes and Hobgood, 1966; Koli and Morrill, 1976; Brashears et al., 1986; etc.). Narrow row cotton spacing has shown definite advantages in California (George et al., 1978; Curley et al., 1982; El-Zik et al., 1982).

Hawkins and Peacock (1983) provided a literature review of most of the early narrow row agronomic research on cotton. Research by Buxton et al. (1977), Buxton et al. (1979), Koli and Morrill (1976), Constable (1977a, 1977b), and Francois (1982) indicates that narrow row spacings less than 1.0 m generally increase yields by 10 to 20% with moderate yield effects for plant populations above normal levels; however, plant population was reported to affect boll and fiber properties.

Reduced irrigation requirements are widely attributed to narrow row cotton systems, particularly in a short-season production system. However, limited research is available to document such claims (Grimes and Dickens, 1977; Bordovsky et al., 1974; Fangmeier and Mohammed, 1977). Although considerable research has been conducted on narrow row cotton in the San Joaquin Valley of California, little information is available on the irrigation management response of cotton grown in narrow row culture. The purpose of this paper is to summarize three experiments conducted from 1981

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through 1983 on the response of narrow row cotton to irrigation management under both trickle and furrow irrigation methods in the semiarid environment of the San Joaquin Valley in California.

## EXPERIMENTAL PROCEDURES

Three experiments were conducted at the University of California West Side Field Station near Five Points, CA, during the 1981 through 1983 growing seasons. All the experiments were conducted on Panoche clay loam soil (Typic Torriorthents), which has a water holding capacity of about 400 mm over a 2.5-m profile depth and offers no major restriction to cotton rooting (Grimes et al., 1975). Cotton rooting at this location generally can exceed 2 m. Additional soils information is available from Nielsen et al. (1964, 1973). Each experiment began with a preplant irrigation designed to refill the 2-m soil profile. Plant populations in each experiment were hand thinned following emergence to about 9 to 11 plants/m<sup>2</sup>, which was reported by Buxton et al. (1977) to be optimum for western cotton production. Each experiment had east-west row direction, and the field slope was 0.4%. Cultural operations were performed uniformly with conventional farm machinery. Water use (evapotranspiration) was estimated by water balance techniques utilizing soil water content measurements determined by field-calibrated neutron probes. The water balance assumed that deep percolation beneath 3.0 m was negligible. The furrow irrigated plots had bordered rows to prevent runoff. Cotton was harvested by a brush-type stripper (Kepner et al., 1979) with lint turnout determined by ginning a 2.7-kg seed cotton sample taken from each plot. Sample ginning was performed at the United States Cotton Research Station at Shafter, California.

### Experiment A

The first experiment used furrow irrigation on 91-m length rows. The imposed irrigation treatments were as follows:

1. Full irrigation consisting of three postplant irrigations.
2. Limited irrigation consisting of two postplant irrigations.
3. No postplant irrigations.

The irrigation treatments were based on the results from Grimes and Dickens (1977), which indicated that at this location two to three furrow-applied irrigations are optimum for high yields of narrow row cotton and that water deficits should be avoided during flowering. The full irrigation treatment received irrigations at the early squaring, peak bloom, and peak boll production growth stages. The limited irrigation treatment received applications at peak flowering and peak boll production growth stages. Each treatment was replicated three times in a randomized, complete block design with individual plot sizes of 10 by 91 m. Nitrogen was applied prior to planting at the rate of 140 kg N/ha. Cotton (*Gossypium hirsutum* L., c.v. Acala SJ-2) was planted on April 15, 1981, in 0.5-m rows on 1.0-m beds (two rows per bed). The field was sprinkler irrigated with 46 mm of water following planting to ensure uniform emergence. All other irrigations were applied to the 1.0-m spaced furrows by gated pipe. The irrigation applications were metered by a time-volume estimation procedure.

Soil water content measurements were made using the neutron method weekly, 1 day before and 2 to 3 days after each irrigation. Measurements were taken at 0.20-m increments from 0.20- to 3.0-m depths.

Two yield samples were harvested by machine from each plot on October 13, 1981. Each sample represented eight narrow rows (four beds) that were 90 m in length. The total harvested area per plot was 720 m<sup>2</sup>. The harvested mass was determined with a dumping basket trailer scale. Additional details are found in Howell et al. (1984).

### Experiment B

This experiment was similar to Experiment A, using a row length of 91 m and furrow irrigations applied by gated pipe. The imposed irrigation treatments were as follows:

1. Full irrigation consisting of three postplant irrigations.
2. Limited irrigation consisting of two postplant irrigations.
3. A single postplant irrigation.

The full irrigation treatment received irrigations applied at early squaring, peak flowering, and peak boll production periods. The limited irrigation treatment received irrigations applied at peak flowering and peak boll development periods. The single irrigation was applied at the peak flowering period. Each treatment was replicated three times in a randomized, complete block design with randomly installed split-plots using three Acala varieties (SJ-2, SJC-1, and DPL-90). Nitrogen was preplant applied at the rate of 150 kg N/ha. The cotton was planted on April 29, 1982, in 0.5-m rows on 1.0-m beds (two rows per bed). Each plot consisted of 16 rows (eight beds) of the test variety and four buffer rows (two beds) of the SJ-2 variety. The field was furrow irrigated with 50 mm of water following planting to ensure uniform emergence. Irrigations were applied and metered as in Experiment A.

Soil water content measurements were made with the neutron method periodically (7- to 10-day intervals), before, and after each irrigation. Measurements were taken at 0.25 m and from 0.45- to 2.85-m depths in 0.3-m increments.

Two yield samples were machine harvested from each subplot on October 19 and 20, 1982. Each sample represented four rows (two beds) that were 25 m in length. The total harvested area per plot was 100 m<sup>2</sup>.

### Experiment C

The third experiment was conducted during 1982 and 1983 using trickle irrigation applied to 27-m length rows. The imposed irrigation treatments were as follows:

1. Irrigated twice a week with trickle tubes spaced 2.0 m apart in the alternate furrows (every other furrow).
2. Irrigated twice a week with trickle tubes spaced 2.0 m apart and pulse-irrigated (hourly irrigation pulses applied during the day) at the peak boll load period.
3. Irrigated every 2 weeks with trickle tubes spaced 1.0 m apart in each furrow (simulated common furrow irrigation pattern).

The pulsing applications on treatment 2 were designed to minimize any diurnal soil water deficits on the crop during its peak photosynthetic demand stage. The trickle irrigation tubing was 13 mm I.D. polyethylene tubing with inline emitters (2 L/h nominal flow rate) spaced at

0.46-m intervals. The operating pressure was 103 kPa, and the flow rate into each plot was controlled at 908 L/h. The irrigation water volume was measured by two inline domestic-type water meters. The trickle irrigations were initiated in each treatment in July at the early-squaring growth stage and continued from early July through August each year. The irrigation application amounts were based on measured soil water. Each treatment was replicated three times in a randomized, complete block design with an individual plot size of 16 rows (eight beds) by 27 m. Nitrogen was applied at the rate of 200 kg N/ha, with the irrigation water in the form US-28 (Urea Sulfuric Acid, 28% N) in both years. Acala cotton (SJ-2) was planted on April 29, 1982, and April 30, 1983, respectively. All plots were irrigated in both years, with 25 mm of water applied by trickle irrigation following planting to ensure uniform emergence.

Soil water contents were measured by the neutron method weekly (before an irrigation) at 0.3-m increments from 0.15 to 2.85 m. Yield was determined by machine harvesting the center four rows (two beds) of each plot for a total harvested area of 50 m<sup>2</sup> on October 20, 1982, and November 3, 1983, respectively. Additional details are found in Meron et al. (1984).

## RESULTS AND DISCUSSION

The climatic regime in the San Joaquin Valley is characterized as Mediterranean, with the majority of the rainfall received prior to cotton planting. The summer growing conditions are usually warm and dry. Daily maximum temperatures are usually in the 32 to 37°C range, with little rainfall expected from May through August. Weather conditions during these studies (1981-1983) were typical for this region. The cotton growing seasons received total rainfall amounts of 38, 29, and 59 mm for the respective years. The cotton growing season is typified by generally clear sky conditions, dewpoint temperatures in the range of 5 to 10°C, and moderate windspeeds in the range of 1.5 to 3.0 m/s at 2-m elevation above ground.

TABLE 1. SUMMARY OF WATER APPLICATION COMPONENTS FOR THE EXPERIMENTS

Experiment	Year	Treatment	Applied water			
			Preplant	Seasonal	Rainfall	Total
			----- mm -----			
A	1981	1. full	274	420	38	732
		2. limited	274	287	38	599
		3. none	274	46	38	358
B	1982	1. full	381	340	29	750
		2. two	381	226	29	636
		3. one	381	142	29	552
C	1982	1. 2/wk	213	422	29	664
		2. 2/wk pulse	213	441	29	683
		3. 14 day	213	399	29	641
C	1983	1. 2/wk	45	421	50	516
		2. 2/wk pulse	45	414	50	509
		3. 14 day	45	390	50	485

## Crop Water Use

Table 1 presents a summary of the total water applications for each treatment during the three experiments. Preplant irrigation is widely practiced in the San Joaquin Valley to fully recharge and leach the soil profile before cotton is planted. The preplant applications varied from 318 mm in Experiment B in 1982 to only 45 mm in Experiment C in 1983. The unusually small amount of preplant irrigation used in 1983 was due to the record winter rainfall (300 mm) received at this site. The preplant irrigations generally refilled the soil profile to at least a 2-m depth. The total water application ranged from 358 mm for preplant only treatment in Experiment A in 1981, to 750 mm for the full irrigation treatment in Experiment B in 1982.

Table 2 presents the summary of the water balance components of each experiment including total growing season applied water, profile soil water depletion, and growing season evapotranspiration. Cotton irrigation termination in this region has been shown by Grimes and Dickens (1974) to depend on soil water holding

TABLE 2. SUMMARY OF GROWING SEASON APPLIED WATER, PROFILE SOIL WATER DEPLETION, AND EVAPOTRANSPIRATION FOR THE EXPERIMENTS

Cotton cultivar											
Experiment	Year	Treatment	SJ-2			SJC-1			DPL-90		
			AW*	SW*	ET*	AW	SW	ET	AW	SW	ET
-----mm-----											
A	1981	1. full	458	320	778						
		2. limited	325	269	594						
		3. none	84	357	441						
B	1982	1. full	369	388	757	369	351	720	369	335	704
		2. two	255	470	725	255	357	612	255	437	692
		3. one	171	452	623	171	375	546	171	416	587
C	1982	1. 2/wk	451	220	671						
		2. 2/wk pulse	470	222	692						
		3. 14 day	428	189	617						
C	1983	1. 2/wk	471	188	659						
		2. 2/wk pulse	464	193	657						
		3. 14 day	440	201	641						

\*AW is total growing season applied water (irrigation plus rainfall); SW is growing season profile soil water depletion; and ET is the water used by the crop in evapotranspiration (AW plus SW with drainage assumed to be negligible).

characteristics. Generally, with a recharged soil profile, the last irrigation of cotton on the Panoche clay loam soil will fall in late August. Since furrow irrigations needed to be at least 75 mm for good uniformity on these plots, the last furrow irrigation was applied about 2 weeks before the last trickle irrigation application. This resulted in less crop extraction of the available soil water at the end of the season under trickle irrigation compared to the furrow irrigation; however, this should be offset by the reduced requirement for preplant irrigation the following spring. The total water application amounts were within a narrow range for the "fully" irrigated treatments of the various experiments. Likewise, the evapotranspiration for these "fully" irrigated furrow treatments was similar, varying from 778 mm for Experiment A, Treatment 1 to 757 mm to Experiment B, Treatment 1 in 1982. In comparison, the "fully" irrigated trickle treatments used 659 to 671 mm in the 2 years. Since the irrigation systems used in these experiments were managed and operated very efficiently, this range expresses differences in soil water evaporation rather than any crop transpiration differences (crop yields as shown later were similar). In 1982, Experiments B and C can be qualitatively compared (a statistical comparison is not valid) since the two experimental fields were only about 400 m apart and were planted and harvested alike. In 1982, the mean decrease in the evapotranspiration of the trickle irrigated treatments in Experiment C and the "fully" furrow irrigated Acala cultivars in Experiment B was 67 mm. The lint yield of the furrow irrigated SJ-2 cultivar was 107 kg/ha less than the mean of the trickle irrigated treatments. Both of the newer Acala cultivars (SJC-1 and DPL-90) had slightly less evapotranspiration and yield than the SJ-2 variety.

### Crop Yield

Table 3 presents the summary of the cotton lint yields from each experiment. Lint yields were limited, to some extent, in the 1981 and 1983 experiments due to moderate levels of verticillium wilt. No verticillium wilt symptoms were evident in 1982 at the site of Experiment B. Severe verticillium wilt symptoms were evident in the fully irrigated treatment in Experiment A. Nevertheless,

TABLE 3. SUMMARY OF LINT COTTON YIELD DATA FROM THE EXPERIMENTS

Experiment	Year	Treatment	Cotton cultivar		
			SJ-2	SJC-1	DPL-90
----- Lint yield, kg/ha -----					
A	1981	1. full†	1,583 a*		
		2. limited‡	1,423 a		
		3. none‡	601 b		
B	1982	1. full	1,928 ab	1,602 c	1,614 bc
		2. two	1,949 a	1,651 bc	1,710 abc
		3. one	1,655 abc	1,470 c	1,588 c
C	1982	1. 2/wk‡	1,941 b		
		2. 2/wk‡	2,145 a		
		pulse			
C	1983	3. 14 day‡	2,020 ab		
		1. 2/wk‡	1,619 ab		
		2. 2/wk‡	1,492 b		
C	1983	pulse			
		3. 14 day‡	1,779 a		

\*Means followed by same letter are not statistically different at the 0.05 level according to the Duncan multiple comparison test. Statistical comparisons are valid only within an experiment.

†Verticillium wilt present at severe levels.

‡Verticillium wilt present at moderate level.

lint yields were excellent for the growing conditions commonly encountered in the San Joaquin Valley. The 1982 lint yields of SJ-2 cultivars of the "well-irrigated regimes" in Experiments B and C ranged from 1,928 to 2,145 kg/ha (3.6 to 4.0 bales/acre, based on 480-lb bales), which is a high yield for San Joaquin Valley cotton. Average San Joaquin Valley lint yields are usually about 1,050 to 1,350 kg/ha, with normal yields on the west side of the valley being 1,500 kg/ha. The lint yields reported here are about 10 to 25% greater than comparable conventional-spaced row plot yields at the research station. Experiment B showed that two irrigations produced the greatest lint yield in all three Acala cultivars, but these yields were not statistically different at the 5% level of confidence. Although a direct statistical comparison cannot be made for lint yields between the different irrigation methods, the comparison of a "simulated" furrow irrigation treatment (Treatment 3 in Experiment C) and the other trickle irrigation treatments indicates no significant differences. This result indicates that yield differences due to irrigation method should be expected only when irrigation efficiency or uniformity is limiting. This conclusion is evident by the lack of any lint yield difference between trickle irrigation frequencies from twice per week to one irrigation per 2 weeks. Therefore, maximum lint cotton yields in narrow rows in the San Joaquin Valley require water applications greater than 650 mm to achieve evapotranspiration amounts of at least 600 mm. Irrigation application uniformity and efficiency dictate the gross irrigation necessary to achieve maximum crop production.

### Lint Yield-Water Use Relationships

The relationship between total applied water (defined as the total of preplant irrigation, seasonal irrigation and seasonal rainfall) and lint yield for the SJ-2 cultivar is presented in Fig. 1. The linear correlation fit the data with a coefficient of determination of 0.55. The root mean square error was 260 kg/ha. Considering that the preplant irrigation amount for Experiment C in 1983 was about 150 mm lower than in the other years, a more accurate relationship probably exists than that illustrated in Fig. 1. However, it is clear that a total water application of at least 650 to 750 mm is necessary to

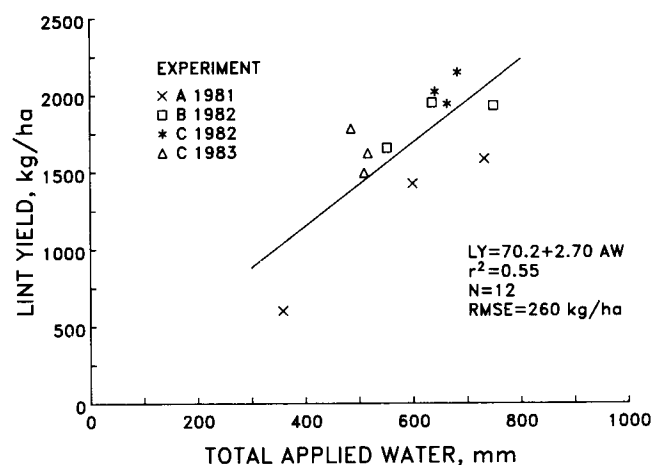


Fig. 1—Relationship between narrow row cotton lint yield of SJ-2 cultivar and total applied water for the experiments.

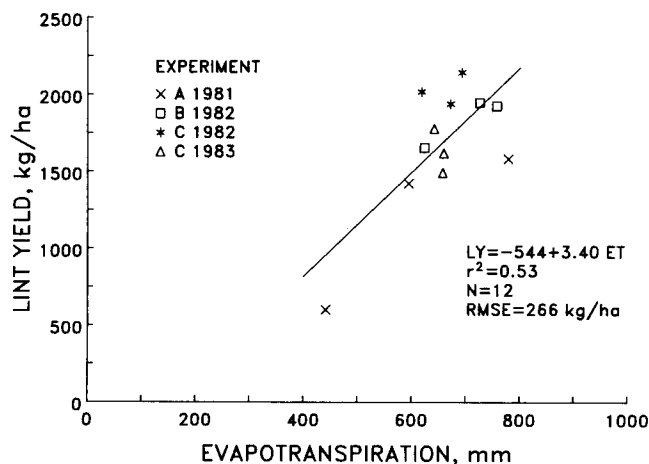


Fig. 2—Relationship between narrow row cotton lint yield of SJ-2 cultivar and evapotranspiration for the experiments.

produce maximum lint yield of narrow row cotton at this location.

The linear correlation between lint yield of the SJ-2 cultivar and estimated evapotranspiration, as determined by water balance, is illustrated in Fig. 2 for these experiments. Considering that most of the yield and evapotranspiration values were clustered closely together and that the 1981 fully-irrigated treatment yield was affected by verticillium wilt, the relationship is relatively well defined by a linear correlation. The coefficient of determination was 0.53, and root mean square error was 266 kg/ha when all 12 data pairs were included. When the 1981 fully irrigated treatment in Experiment A was excluded from the regression due to its high verticillium wilt incidence (the resulting equation was  $LY = -1,155 + 4.42 ET$ ), the coefficient of determination increased to 0.73 and the root mean square error decreased to 230 kg/ha. Pruitt et al. (1970) presented the lint yield-water use relationship,  $LY = -498 + 3.14 ET$ , based on 1.0-m spaced cotton rows at this same location. The calculated yield increases at 700 mm of evapotranspiration by decreasing the normal row spacing, using the relationship of Pruitt et al. (1970), to narrow row spacing, using the relationships presented here, is 8 to 14%, depending on whether Treatment 1 of Experiment A is included or not. This estimated yield increase, although less than other direct comparisons for narrow row cotton, should be important to cotton producers seeking better and more efficient production systems.

The water use efficiency (lint yield per unit evapotranspiration) and irrigation water use efficiency (lint yield per unit of total applied water) are summarized for each experiment in Fig. 3. The mean water use efficiency of all the irrigation experiments (excluding the no postplant treatment in the 1981 experiment) was 0.265 kg/m<sup>3</sup> with a standard deviation of 0.036 kg/m<sup>3</sup>. The high values for water use efficiency in 1982 for Experiment C indicate what the near potential cotton water use efficiency might be with very high levels of irrigation management, high irrigation efficiency, and high cultural management levels. The water use efficiency for Experiment C in 1982 was greater than the water use efficiency for Experiment B indicating the improvement in irrigation efficiency from furrow to trickle irrigation. This improvement in irrigation

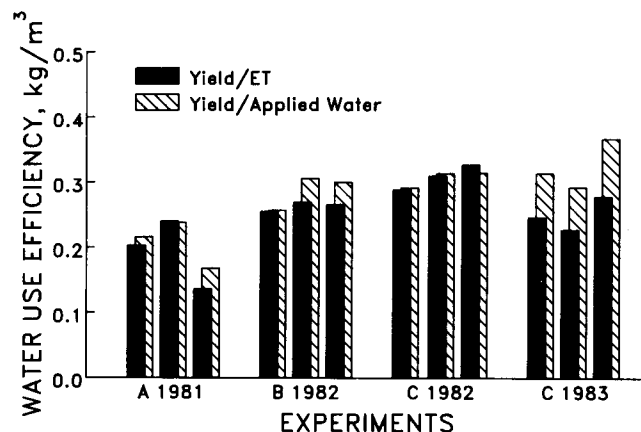


Fig. 3—Water use efficiency (lint yield per unit evapotranspiration) and irrigation water use efficiency (lint yield per unit of applied water) in kg/m<sup>3</sup> for the experiments.

efficiency would be due to the partitioning of soil evaporation and transpiration within the total evapotranspiration. It should be kept in mind that the comparison between trickle and furrow irrigation is with very efficient furrow irrigation having short runs and uniform applications. The mean irrigation water use efficiency of all the irrigation experiments (excluding the no postplant treatment in the 1982 experiment) was 0.292 kg/m<sup>3</sup> with a standard deviation of 0.042 kg/m<sup>3</sup>. The increase in irrigation water use efficiency over the water use efficiency is due partly to the small preplant irrigation in 1983 and the effects of crop water extraction from stored soil water. The similarity between the irrigation water use efficiency and water use efficiency in 1981 and 1982 indicates the high irrigation efficiencies that existed in the experiments.

## CONCLUSIONS

Narrow row cotton production systems offer producers several distinct options. These studies and many previous studies indicate that narrow row cotton production (using 0.5-m row spacing) can increase lint yields; however, water use may not be decreased under full-season maximum production levels.

Specific conclusions from these experiments are:

1. Total seasonal water availability (preplant and seasonal irrigations plus efficient rainfall) for narrow row cotton should exceed 650 mm in the San Joaquin Valley to produce near maximum lint yields.
2. Crop evapotranspiration amounts between 650 and 700 mm produce near maximum lint yields of narrow row cotton in the San Joaquin Valley.
3. Trickle irrigation frequency for narrow row cotton on the Panoche clay loam soil in the San Joaquin Valley could be as long as 1 to 2 weeks without decreasing lint yield if the application amounts are sufficient to meet the crop water use.
4. Lint yields of narrow row cotton in these studies were not greatly different under "well-watered" management for both a trickle system and a highly efficient and uniform furrow irrigation system.

## References

1. Bordovosky, D. G., W. R. Jordan, E. A. Hiler, and T. A. Howell. 1974. Choice of irrigation timing indicator for narrow row cotton. *Agron. J.* 66:88-91.

2. Brashears, A. D., I. W. Kirk, and E. B. Hudspeth, Jr. 1968. Effects of row spacing and plant populations on double-row cotton. *Tex. Agric. Exp. Stn. MP-872*.
3. Buxton, D. R., R. E. Briggs, L. L. Patterson, and S. D. Watkins. 1977. Canopy characteristics of narrow-row cotton as influenced by plant density. *Agron. J.* 69:929-933.
4. Buxton, D. R., L. L. Patterson, and R. E. Briggs. 1979. Fruiting pattern in narrow-row cotton. *Crop Sci.* 19:17-22.
5. Constable, G. A. 1977a. Narrow row cotton Manoi Valley. I. Growth, yield, and quality of four cultivars. *Aust. J. Exp. Agric. and Husb.* 17:135-142.
6. Constable, G. A. 1977b. Narrow row cotton Manoi Valley. II. Plant population and row spacing. *Aust. J. Exp. Agric. and Husb.* 17:143-148.
7. Curley, R. G., C. R. Brooks, R. A. Kepner, K. El-Zik, A. G. George, T. A. Kerby, O. D. McCutcheon, L. K. Stromberg, R. N. Vargas, B. L. Weir, D. L. West, and M. K. Brittan. 1982. Long-term study reaffirms yield increases of narrow row cotton. *Calif. Agric.* 36:8-10.
8. El-Zik, K., M. K. Brittan, C. Brooks, R. G. Curley, A. G. George, R. A. Kepner, T. A. Kerby, O. D. McCutcheon, L. K. Stromberg, R. N. Vargas, D. West, and B. Weir. 1982. Effects of row spacing on cotton yield, quality, and plant characteristics. *Univ. Calif., Coop. Ext. Serv. Bull.* 1903. 8 p.
9. Fangmeier, D. D., and R. A. Mohammed. 1977. Irrigation management of short-season high-population cotton. *TRANSACTIONS of the ASAE* 20(5):869-872.
10. Francois, L. E. 1982. Narrow row cotton (*Gossypium hirsutum* L.) under saline conditions. *Irrig. Sci.* 3:149-156.
11. George, A., O. D. McCutcheon, C. R. Brooks, R. G. Curley, K. El-Zik, and R. E. Johnson. 1978. Summary report of narrow row field trials, 1971-1973. *Univ. Calif., Coop. Ext. Serv. Special Rep.* 3205.
12. Grimes, D. W., and D. L. Dickens. 1974. Dating termination of cotton irrigation from soil water-retention characteristics. *Agron. J.* 66:403-404.
13. Grimes, D. W., and D. L. Dickens. 1977. Irrigation water management of cotton for a planting configuration and variety conducive to short-season development. *Univ. Calif., Water Sci. and Engr. Paper* 7003. 74 p.
14. Grimes, D. W., R. J. Miller, and P. J. Willey. 1975. Cotton and corn root development in two field soils of different strength. *Agron. J.* 67:519-523.
15. Hawkins, B. S., and H. A. Peacock. 1973. Influence of row width and population density on yield and fiber characteristics of cotton. *Agron. J.* 65:47-51.
16. Howell, T. A., K. R. Davis, R. L. McCormick, H. Yamada, V. T. Walhood, and D. W. Meek. 1984. Water use efficiency of narrow row cotton. *Irrig. Sci.* 5:195-214.
17. Kepner, R. A., R. G. Curley, C. R. Brooks, and V. T. Walhood. 1979. A brush-type stripper for double-row cotton. *TRANSACTIONS of the ASAE* 22(6):1234-1237.
18. Kerby, T. A., L. M. Carter, S. E. Hughes, and C. K. Bragg. 1986. Alternate harvesting systems and cotton quality. *TRANSACTIONS of the ASAE* 29(2):407-412.
19. Kohel, R. J., and C. F. Lewis (eds.). 1984. *Cotton*. Agron. Mono. 24. Am. Soc. Agron., Madison, WI, 605 p.
20. Koli, S. E., and L. G. Morrill. 1976. Influence of nitrogen, narrow rows, and plant population on cotton yield and growth. *Agron. J.* 68:897-901.
21. Longnecker, D. E., E. L. Thaxton, J. L. Hefner, Jr., and P. J. Lylerly. 1970. Variable row spacing of irrigated cotton. *Tex. Agric. Exp. Stn. Bull.* 1102.
22. Meron, M., C. J. Phene, T. A. Howell, K. R. Davis, and D. W. Grimes. 1984. Scheduling of drip irrigated narrow row cotton. In *Water: today and tomorrow*. Proc. ASCE Irrig. Drain. Div. Conf., pp. 314-322.
23. Nielsen, D. R., J. M. Davidson, J. W. Biggar, and R. J. Miller. 1964. Water movement through Panoche clay loam soil. *Hilgardia* 35:491-506.
24. Nielsen, D. R., J. W. Biggar, and K. T. Erh. 1973. Spatial variability of field-measured soil-water properties. *Hilgardia* 42:215-260.
25. Pruitt, W. O., J. I. Stewart, R. M. Hagan, R. H. Cuenca, T. Hsiao, and P. Martin. 1979. Determination and utilization of water production functions for principal California crops. W-67 California Contributing Project (by R. M. Hagan and T. C. Hsiao). *Univ. Calif., Davis*, pp. 14-34.
26. Wilkes, L. H., and P. Hobgood. 1966. Broadcast and narrow-row cotton in the Brazos River Valley. *Tex. Agric. Ext. Stn. Rep.* 2428.